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Set Name side by side	Query	Hit Count	Set Name result set
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L52	L51 and ag$3	31	L52
L51	L50 and adjust$5	40	L51
L50	display with diodes and pixels with circuit and (phototransistor or photoresistor or photodiode)	73	L50
L49	display with pixels with circuit and (phototransistor or photoresistor or photodiode)	107	L49
L48	Electroluminesent with display and (phototransistor or photoresistor or photodiode)	2	L48
L47	L46 and (photoresistor or photodiode or photosensor)	1	L47
L46	5973456	11	L46
L45	5973456.pn.	1	L45
L44	6057647.pn.	1	L44
L43	6191764.pn.	1	L43

L42	4975691.pn.	1	L42
L41	5973456.pn.	1	L41
L40	6057647.pn.	1	L40
L39	6191764.pn.	1	L39
L38	L37 and electrodes	7	L38
L37	L35 and ag$3	9	L37
L36	L35 and age	0	L36
L35	L34 and correct$4	9	L35
L34	L32 and adjust$5	13	L34
L33	L32 and correct$3 with adjust$5	1	L33
L32	L31 and (photosensor or photoresistor or photodiode)	21	L32
L31	display with LEDs and driv$ with pixels with circuit	219	L31
L30	L29 and ag$3	10	L30
L29	display with EL with pixels and (photodiode or photoresistor)	12	L29
L28	display with pixel with circuit and driv$ with LED and photosensor	1	L28
L27	display with pixel with circuit and driv$ with LED and photosensor	1	L27
L26	display with pixel with circuit and driv$ with LED and age	2	L26
L25	L17 and detect$4	0	L25
L24	L19 and detect$4	0	L24
L23	L19 and sensor	0	L23
L22	L19 and photo$	0	L22
L21	L19 and phot$	0	L21
L20	L19 and photosensor	0	L20
L19	L17 and correct$	1	L19
L18	L17 and correct$ with adjust$	0	L18
L17	display with pixel with circuit and driv$ with LED and age	2	L17
L16	L15 and adhesive	8	L16
L15	L14 and black with matrix	17	L15
L14	L13 and cover with plate	88	L14
L13	tiles with display	928	L13
L12	L11 and black with matrix	3	L12
L11	tiled with flat with panel with display	45	L11
L10	tiled with flat with panel with display and black with matrix	3	L10
L9	tiled with flat with panel and black with matrix	3	L9
L8	tiled with flat with panel and two with display with tiles and black with matrix	0	L8
L7	L6 and OLED	0	L7
L6	L3 and pixels	28	L6
L5	L3 and optical with integra$ with plate	0	L5
L4	L3 and OIP	0	L4

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L52: Entry 6 of 31 File: USPT Oct 16, 2001

DOCUMENT-IDENTIFIER: US 6303943 B1
TITLE: Organic diodes with switchable photosensitivity useful in photodetectors

Brief Summary Text (3):
The present invention relates to organic, polymer-based photodiodes and to their use in one and two dimensional image sensors. In more preferred embodiments, it concerns organic polymer-based photodiodes which are voltage switchable and which may be arrayed as image sensors in the form of a column-row (x-y) passively addressable matrix, where the x-y addressable organic image sensors (image arrays) have full-color or selected-color detection capability, or as linear photodiode arrays.

Brief Summary Text (5):
The development of image array photodetectors has a relatively long history in the solid state device industry. Early approaches to imaging technology included devices based on thermal effects in solid state materials. These were followed by high sensitivity image arrays and matrices based on photodiodes and charge-coupling devices ("CCDs") made with inorganic semiconductors. These arrays can be simple linear (or "one dimensional") arrays which scan an image or they can be two dimensional, like the image.

Brief Summary Text (6):
Photodiodes made with inorganic semiconductors, such as silicon, represent a class of high quantum yield, photosensitive devices. They have been used broadly in visible light detection applications in the past decades. However, they characteristically present a flat current-voltage response, which makes it difficult to use them in fabricating high pixel density, x-y matrix-addressable passive image sensors. An "x-y" matrix is a two dimensional array with a first set of electrodes perpendicular to a second set of electrodes. When passive devices such as resistors, diodes or liquid crystal cells are used as the pixel elements at the intersection points, the matrix is often called a "passive" matrix in contrast to an "active" matrix in which active devices, such as transistors, are used to control the turn-on for each pixel.

Brief Summary Text (7):
To effectively address an individual pixel from the column and row electrodes in a two dimensional passive matrix, the pixel elements must exhibit strongly nonlinear current-voltage ("I-V") characteristics or an I-V dependence with a threshold voltage. This requirement provides the foundation for using light-emitting diodes or liquid crystal cells to construct passive x-y addressable displays. However, since the photoresponse of inorganic photodiodes is voltage-independent in reverse bias, photodiodes made with inorganic semiconductor crystals are not practical for use in high pixel density, passive image sensors--there is too much cross-talk between pixels. To avoid cross-talk, existing two dimensional photodiode arrays made with inorganic photodiodes must be fabricated with each pixel wired up individually, a laborious and costly procedure. In the case of such individual connections, the number of input/output leads is proportional to the number of the pixels. The number of pixels in commercial two dimensional photodiode arrays is therefore limited to .ltoreq.16.times.16=256 due to the difficulties in manufacturing and in making inter-board connections. Representative commercial photodiode arrays include the Siemens KOM2108 5.times.5 photodiode array, and the Hamamatsu S3805 16.times.16 Si photodiode array.

Brief Summary Text (11):

Photodiodes made with organic semiconductors represent a novel class of photosensors with promising process advantages. Although there were early reports, in the 1980s, of fabricating photodiodes with organic molecules and conjugated polymers, relatively small photoresponse was observed [for an review of early work on organic photodiodes, see: G. A. Chamberlain, Solar Cells 8, 47 (1983)]. In the 1990s, there has been progress using conjugated polymers as the active materials; see for example the following reports on the photoresponse in poly(phenylene vinylene), PPV, and its derivatives,: S. Karg, W. Riess, V. Dyakonov, M. Schwoerer, Synth. Metals 54, 427 (1993); H. Antoniadis, B. R. Hsieh, M. A. Abkowitz, S. A. Jenekhe, M. Stolka, Synth. Metals 64, 265 (1994); G. Yu, C. Zhang, A. J. Heeger, Appl. Phys. Lett. 64, 1540 (1994); R. N. Marks, J. J. M. Halls, D. D. D. C. Bradley, R. H. Frield, A. B. Holmes, J. Phys.: Condens. Matter 6, 1379 (1994); R. H. Friend, A. B. Homes, D. D. C. Bradley, R. N. Marks, U.S. Pat. No. 5,523,555 (1996)].

Brief Summary Text (12):
The photosensitivity in organic semiconductors can be enhanced by excited-state charge transfer; for example, by sensitizing the semiconducting polymer with acceptors such as C.sub.60 or its derivatives [N. S. Sariciftci and A. J. Heeger, U.S. Pat. No. 5,331,183 (Jul. 19, 1994); N. S. Sacriftci and A. J. Heeger, U.S. Pat. No. 5,454,880 (Oct. 3, 1995); N. S. Sariciftci, L. Smilowitz, A. J. Heeger and F. Wudl, Science 258, 1474 (1992); L. Smilowitz, N. S. Sariciftci, R. Wu, C. Gettinger, A. J. Heeger and F. Wudl, Phys. Rev. B 47, 13835 (1993); N. S. Sariciftci and A. J. Heeger, Intern. J. Mod. Phys. B 8, 237 (1994)]. Photoinduced charge transfer prevents early time recombination and stabilizes the charge separation, thereby enhancing the carrier quantum yield for subsequent collection [B. Kraabel, C. H. Lee, D. McBranch, D. Moses, N. S. Sariciftci and A. J. Heeger, Chem. Phys. Lett. 213, 389 (1993); B. Kraabel, D. McBranch, N. S. Sariciftci, D. Moses and A. J. Heeger, Phys. Rev. B 50, 18543 (1994); C. H. Lee, G. Yu, D. Moses, K. Pakbaz, C. Zhang, N. S. Sariciftci, A. J. Heeger and F. Wudl, Phys. Rev. B. 48, 15425 (1993)]. By using charge transfer blends as the photosensitive materials in photodiodes, external photosensitivity of 0.2-0.3 A/Watt and external quantum yields of 50-80% el/ph have been achieved at 430 nm at low reverse bias voltages [G. Yu, J. Gao, J. C. Hummelen, F. Wudl and A. J. Heeger, Science 270, 1789 (1995); G. Yu and A. J. Heeger, J. Appl. Phys. 78, 4510 (1995); J. J. M. Halls, C. A. Walsh, N. C. Greenham, E. A. Marseglia, R. H. Frield, S. C. Moratti and A. B. Holmes, Nature 376, 498 (1995)]. At the same wavelength, the photosensitivity of the UV-enhanced silicon photodiodes is .about.0.2 A/Watt, independent of bias voltage [S. M. Sze, Physics of Semiconductor Devices (Wiley, N.Y. 1981) Part 5]. Thus, the photosensitivity of thin film photodiodes made with polymer charge transfer blends is comparable to that of photodiodes made with inorganic semiconducting crystals. In addition to their high photosensitivity, these organic photodiodes show large dynamic range; relatively flat photosensitivity has been reported from 100 mW/cm.sup.2 down to nW/cm.sup.2 ; i.e., over eight orders of magnitude [G. Yu, H. Pakbaz and A. J. Heeger, Appl. Phys. Lett. 64, 3422 (1994); G. Yu, J. Gao, J. C. Hummelen, F. Wudl and A. J. Heeger, Science 270, 1789 (1995); G. Yu and A. J. Heeger, J. Appl. Phys. 78, 4510 (1995)]. The polymer photodetectors can be operated at room temperature, and the photosensitivity is relatively insensitive to the operating temperature, dropping by only a factor of 2 from room temperature to 80 K [G. Yu, K. Pakbaz and A. J. Heeger, Appl. Phys. Lett. 64, 3422 (1994)].

Brief Summary Text (13):
As is the case for polymer light-emitting devices [G. Gustafsson, Y. Cao, G. M. Treacy, F. Klavetter, N. Colancri, and A. J. Heeger, Nature 357, 477 (1992); A. J. Heeger and J. Long, Optics & Photonics News, August 1996, p.24], high sensitivity polymer photodetectors can be fabricated in large areas by processing from solution at room temperature. They can be made in unusual shapes (e.g. on a hemisphere to couple with an optical component or an optical system), or they can be made in flexible or foldable forms. The processing advantages also enable one to fabricate the photosensors directly onto optical fibers. Similarly, polymer photodiodes can be hybridized with optical devices or electronic devices, such as an integrated circuits on a silicon wafer. These unique features make polymer photodiodes special for many novel applications.

Brief Summary Text (15):
Recent progress in our group has demonstrated that the photosensitivity in organic

photodiodes can be enhanced by applying a reverse bias. It was further found that the photosensitivity increases with reverse bias voltage, with the increase being independent of incident light intensity [G. Yu, C. Zhang and A. J. Heeger, Appl. Phys. Lett. 64, 1540 (1994); A. J. Heeger and G. Yu, U.S. Pat. No. 5,504,323 (1996)]. This work showed a photosensitivity of .about.90 mA/Watt in poly(2-methoxy-5-(2'-ethyl-hexyloxy)-1,4-phenylene vinylene) ("MEH-PPV")-based thin film devices, such as ITO/MEH-PPV/Ca thin film devices, at 10 V reverse bias (430 nm), corresponding to a quantum efficiency of >20% el/ph. In photodiodes fabricated with poly(3-octylthiophene), photosensitivity over 0.3 A/Watt was observed over most of visible spectral range at -15 V bias [G. Yu, H. Pakbaz and A. J. Heeger, Appl. Phys. Lett. 64, 3422 (1994)].

Brief Summary Text (16):
We have now found that this variable photosensitivity enables on-off voltage-switchable photosensors. At a reverse bias, typically in the range of 2-15 V, the photodiode can be switched on with photosensitivity of 30-300 mA/W. The photosensitivity at a voltage close to the internal (built-in) potential is several orders of magnitude lower, equivalent to zero at the output of a digital read-out circuit. This near zero state can thus be defined as the off state of the photodiode.

Brief Summary Text (17):
These voltage-switchable, organic photodiodes can serve as individual pixels in passive diode arrays. These arrays can be in the form of x-y addressable arrays with anodes connected via row (column) electrodes and cathodes connected via column (row) electrodes. Every pixel can be selected, and the information (intensity of the incident light) at each pixel can be read out without crosstalk. Alternatively, the voltage-switchable, organic photodiodes can be arrayed in a linear manner.

Brief Summary Text (19):
The photoactive layer employed in these switchable photodiodes is made up of organic materials. These take numerous forms. They can be conjugated semiconducting polymers or polymer blends. For donor-acceptor blends with polymeric donors, the acceptor can be a polymer, macromolecule, oligomer or small molecule (monomers). Alternatively, molecular donor/polymeric acceptor systems also work well. The higher molecular weight component in many cases provides mechanical strength and prevents phase changes. The donor-acceptor blends can also be made with small molecule donors and acceptors that are well known in the art. Examples of the molecular and oligomeric donors include anthracene and its derivatives, pinacyanol and its derivatives thiophene oligomers (such as sexithiophene.6T, and octylthiophene, 8T) and their derivatives and the like, phenyl oligomers (such as sexiphenyl or octylphenyl) and the like. Examples of molecular acceptors include fullerenes (such as C.sub.60 and their functional derivatives), Alq.sub.3 -type organometallic molecules and the like. In addition, one can employ multiple layers of organic semiconducting materials in donor/acceptor heterojunction or quantum-well configurations.

Brief Summary Text (21):
In addition, embodiments of the present invention provide organic image sensors with full-color detection capability. In these organic image sensors, a filter panel is made up of red, green and blue color filters which are patterned in a format corresponding to the format of a photodiode array. The panel of patterned filters and the patterned photodiode array are coupled (and coordinated) such that a colored image sensor is formed. The patterned color filter panel can be used directly as the substrate of the image sensor.

Brief Summary Text (22):
Full-color detectivity, is also achieved when red, green and blue colors are detected by three of these photodiodes with spectral response cut-off at 500 nm, 600 nm and 700 nm, respectively. Differentiation operations in the read-out circuit extract the red (600-700 nm), green (500-600 nm) and blue (400-500 nm) signals.

Drawing Description Text (3):
FIG. 1 is a cross-sectional schematic view of a voltage-switchable photodiode of this invention 10 assembled into a circuit. The photocurrent can be read out by a current meter or a read-out device inserted in the loop;

Drawing Description Text (4):
FIG. 2 is a cross-sectional schematic view of a voltage-switchable photodiode 20 in reversed configuration, in which the reversed configuration refers the structure with the transparent electrode contacted with the free surface of the active layer;

Drawing Description Text (5):
FIG. 3 is an exploded schematic view of a 2D image sensor 30 made of an x-y addressable, passive matrix of voltage-switchable photodiodes;

Drawing Description Text (6):
FIG. 4 is an exploded schematic view of a full-color image sensor 40 made with an x-y addressable photodiode matrix coupled to a color filter panel;

Drawing Description Text (7):
FIG. 5 is an exploded schematic view of a full-color image sensor 50 made with an x-y addressable photodiode matrix of which each full-color pixel is made of three photosensitive materials having differing long-wavelength cut-offs such as at 700 nm, 600 nm and 500 nm;

Drawing Description Text (10):
FIG. 8 is a graph of the photocurrcnt (circles) and the dark current (solid line) of a ITO/MEH-PPV:PCBM/Al photodiode. The photocurrent was taken under white light of intensity .about.10 mW/cm.sup.2.

Drawing Description Text (11):
FIG. 9 is a graph of the current-voltage characteristics of an ITO/P3OT/Au photodiode in the dark (circles), and illuminated under .about.10 mW/cm.sup.2 at 633 nm (squares);

Drawing Description Text (12):
FIG. 10 is a graph of the current-voltage characteristics measured between a row electrode and a column electrode from a 7.times.40 photodiode matrix in the dark (lines) and under room light illumination (circles);

Drawing Description Text (13):
FIG. 11 is a schematic representation of the driving scheme for a 7.times.40 photodiode matrix. It will be described in terms of ITO/MEH-PPV:PCBM/Ag switchable photodiodes;

Drawing Description Text (14):
FIG. 12 is a graph of the photoresponse of a voltage-switchable photodiode made with P3OT;

Drawing Description Text (15):
FIG. 13A is a graph of the photoresponse of voltage-switchable photodiodes with spectral response simulating that of human eye, V(.lambda.);

Drawing Description Text (17):
FIG. 14 is a graph of the spectral response of a solar blind UV detector operating at -2V. The photoresponse of the MEH-PPV:C.sub.60 photodiode on ITO/glass substrate and the photoresponse of an UV-enhanced Si photodiode are plotted for comparison;

Drawing Description Text (18):
FIG. 15A is a graph of the response of a PTV photodiode;

Drawing Description Text (19):
FIG. 15B is a graph of the photoresponse of R, G, B photosensors made of PTV photodiodes coupled with a color-filter panel;

Drawing Description Text (21):
FIG. 16A is a graph of normalized spectral response of photodiodes made with PPV (open squares), PDHPV (open circles), and PTV (solid circles);

Drawing Description Text (23):

FIG. 17 is a graph showing I-V response of a photodiode made with PPV in the dark and under illumination;

Drawing Description Text (24):
FIG. 18 is a graph showing I-V response of a photodiode with a donor/acceptor heterojunction structure in the dark and under illumination;

Drawing Description Text (25):
FIG. 19 is a graph of the dark (solid circles) and photocurrents (circles) of a P3HT photodiode under 8 mW/cm.sup.2 broad band white light (400-700 nm);

Drawing Description Text (26):
FIGS. 20A and 20B are cross-sectional schematic views of linear photodiode arrays made with organic semiconductors;

Drawing Description Text (27):
FIG. 21 is a sketch of the circuit used to drive the organic photodiode array;

Drawing Description Text (28):
FIGS. 22A-D show images achieved by a P3OT linear photodiode array of 100 pixels over a 2.5 inch length. FIG. 22A is a red color image; FIG. 22B is a green color image; FIG. 22C is a blue color image; and FIG. 22D is a full-color image recovered by superposing the red, green and blue color images of FIGS. 22A-C;

Drawing Description Text (29):
FIG. 23 is a graph of an optical beam analyzer made with a 1.times.102 polymer photodiode array;

Drawing Description Text (30):
FIG. 24 is a graph of the angular distribution of the light emission from a GaP LED measured with a flexible linear photodiode array;

Drawing Description Text (31):
FIG. 25 is a schematic view of a spectrographer made of P3OT photodiode array;

Detailed Description Text (2):
This invention provides high sensitivity photodiodes with voltage-switchable photosensitivity; the photosensitivity can be switched on and off by the application of selected voltages, thereby reducing cross-talk between pixels in an array of such voltage-switchable photodiodes to acceptable levels. These switchable photosensors enable the fabrication of either one- or two-dimensional (2D), passive image sensors with column-row (x-y) addressability. The voltage-switchable photodetector is constructed in a metal-semiconductor-metal (M--S--M) thin film structure in which an organic film such as a film of semiconducting polymer or a polymer blend is used as the photoactive material. Selected-color or multi-color detection in the visible and near UV can be achieved by coupling the image sensor to an optical filter(s). Fabrication processes for red, green and blue (RGB) and full-color image sensors are described by coupling the x-y addressable polymer diode matrix or linear array with a RGB color filter panel, or by fabricating photodiodes with cut-off of the photoresponse at 500 nm, 600 nm and 700 nm, respectively, onto optically uniform substrates, or by fabricating the photodiodes in microcavity structures with defined spectral responses in the red, green and blue regions.

Detailed Description Text (3):
Voltage-switchable photodiodes make possible 2D image sensors. Using such photodiodes as the sensing elements in a column-row matrix, a 2D x-y addressable, passive image sensor can be constructed which operates without crosstalk. Because of the strong voltage dependence of the photosensitivity, a column of pixels in the 2D photodiode matrix can be selected and turned on with proper voltage bias, leaving the rest of the pixels on other rows insensitive to the incident light. With this type of operation, the physical M row, N column 2D matrix is reduced to N isolated linear diode arrays each with M elements; said isolated linear diode arrays are free from the crosstalk which originates from finite resistance between devices on different columns. With such 2D, passive photodiode arrays, an image can be read out with a pulse train scanning through each column of the matrix. Since the number of

contact electrodes are reduced to N+M in the x-y addressable matrix, compared to N.times.M in the case of individual connection, large size, high pixel density, 2D image arrays become practical (comparable to the high pixel density display arrays made with LCD technology). For example, for a 1000 by 1000 pixel array, the present invention reduces the number or required electrodes by 500 times. The polymer image sensor matrix thus provides a unique approach to fabricating large size, low cost, high pixel density, 2D image sensing arrays with a room temperature manufacturing process.

Detailed Description Text (4):
In addition to being used as the sensing elements in x-y addressable, 2D passive photodiode matrices, these voltage-switchable organic photosensors can also be used to construct linear photodiode arrays. As shown in examples disclosed in this invention, the ratio of I.sub.ph (V.sub.on)/I.sub.ph (V.sub.off) can be more than 3.times.10.sup.7 under photoexcitation of a few mW/cm.sup.2. The large I.sub.ph (V.sub.on)/I.sub.dark (V.sub.on) ratio (>1.3.times.10.sup.5) allows the collection of image data with gray scale resolution of more than 12 bits (12 bit has 4096 gray levels). Linear photodiode arrays made with these materials can be used for high image quality (over 18 bits), full-page color digital image scanners. Contrary to active image sensors, no analog switches are needed to drive these arrays. A digital shift register or a BCD decoder can be used for pixel selection.

Detailed Description Text (5):
The device structure of the linear photodiode array is shown in FIG. 19. Transparent glass or PET films can be used as the substrates. Opaque materials such as silicon wafers can also be used as the substrate material. In this case, the light is incident onto the free surface side as shown in FIG. 20B. When organic PET films are used as substrates, the linear diode array can be made in flexible form. Optical devices with curved surface can also be used as the substrate for these diode arrays; i.e., the linear diode array can be coupled to and integrated with other optical devices in a desired optical arrangement and with a desired optical wavefront.

Detailed Description Text (6):
Linear photodiode arrays can be made in the configurations similar to that shown in FIG. 3 with one row and n columns or with one column and n rows. The cross sectional views of two typical device structures are shown in FIG. 19. The substrates can be transparent or opaque. In a preferred configuration (FIG. 20A), the linear photodiode arrays (210) can be fabricated onto a transparent glass substrate (214) with patterned ITO (211) or other transparent electrode materials (such as conducting polymer electrodes, thin metal films, metal/conducting polymer bilayer electrodes, dielectric film/ITO or metal film/dielectric film bilayer electrodes). The process of ITO patterning is well known in the existing art, and has been used broadly in LCD technologies. The deposition of the organic layer (212) can be achieved by spin casting, drop casting, printing, electrochemical synthesis or vapor deposition. The back electrode, in the form of a narrow bar shape (213), can be vacuum deposited with a simple shadow mask or patterned by means of photolithography. In most applications (especially for larger pixel sizes), no patterning of the sensing material is necessary. This sensing array can be mounted onto a print circuit (PC) board with a driving circuit. Several existing connection techniques (such as card-edge connectors, zebra connectors, bonding tapes, wire bonding, soldering bumper etc.) can be used for interboard connection. The drive circuits can also be arranged (surrounding the sensor array) onto the same substrate. This is especially preferred in arrays with a high pixel density (e.g., >80 pixels/inch). In these cases, the IC chips can be bonded to the glass substrate, and the electrical connections can be achieved via soldering, one-dimensional conducting epoxy or other existing connection technologies.

Detailed Description Text (7):
As demonstrated in the examples herein, the spectral response of the polymer image sensors can cover the entire visible spectrum with relatively flat response. A portion of the visible spectrum can also be selected with a band-pass or low-pass optical filter. Multi-color detection in the visible and the near UV can be achieved by coupling the image sensor with a color-filter panel. A fabrication process for full-color image sensors is described with the x-y addressable polymer diode matrix

and a RGB (red, green, blue) color filter panel. A similar fabrication process can be employed to prepare a linear photodiode array.

Detailed Description Text (9):
In this description of preferred embodiments and in the claims, reference will be made to several defined terms. One group of terms concerns the structure of the voltage-switchable photodiode. A cross-sectional view of the voltage-switchable photodiode is shown in FIG. 1. The voltage-switchable photodiode 10 is constructed using the metal-semiconductor-metal (M--S--M) thin film device configuration. Specifically, the device 10 includes:

Detailed Description Text (11):
Two "contact electrodes" (layers 11, 13) which serve as the anode and cathode of the photodiodes to extract electrons and holes, respectively, from the photoactive layer. One of the electrodes (layer 11 in FIG. 1) is made transparent or semitransparent in the spectral range of interest to allow the incident light 18 to be absorbed in the active layer (12).

Detailed Description Text (14):
As shown in FIGS. 1 and 2, electrodes 11 and 13 are connected to bias voltage source 15 via lines 17 and 17', respectively. Detector 16 (that represents a current meter or a read out device) is wired in series into this circuit to measure the photoresponse generated in the photodiode in response to light 18. This same circuit would be employed in all of the devices (10, 20, 30, 40 and 50) depicted in FIGS. 1-5.

Detailed Description Text (21):
The structure of the x-y addressible, passive photodiode matrix (2D image sensor 30) is depicted in FIG. 3. Shown in FIG. 4 is the structure of a full-color image sensor 40 made with the x-y addressable photodiode matrix. In these devices, the anode and cathode electrodes 11', 13' are typically patterned into rows and columns perpendicular to one another. Patterning of the photoactive layer 12 is not necessary for pixels with sufficient space between adjacent electrodes. Each intersection of the row and column electrodes defines a photosensitive element (pixel) with device structure similar to that shown in FIG. 1 or FIG. 2. The widths of the row and column electrodes 11', 13' define the active area of each pixel.

Detailed Description Text (22):
A matrix of color filters 19 (each pixel of the color filter is comprised of red, green and blue color filters 19') is coupled with the photodiode panel. A separate sheet of color filters similar to that used for color-LCD displays [For a review, see: M. Tani and T. Sugiura, Proceeding of SID, Orlando, Fla. (1994)] can be used for this purpose. In a more preferred embodiment, the color-filter panel can be coated directly onto the substrate for the photodiode matrix. The set of transparent electrodes 11 (for example, made of indium-tin-oxide, ITO) can be fabricated over the color filter coating. In this configuration, high pixel densities with micron-size feature size can be achieved.

Detailed Description Text (24):
Full-color detection can be achieved with an alternative approach 50 as shown in FIG. 5. In this approach, each full-color pixel 12' comprises three photodiodes 12R, 12G and 12B with long wavelength cut-offs at 700, 600 and 500 nm, respectively. These photodiodes are made of three photosensitive materials in the defined areas on the substrate. The patterning of the active layers can be achieved by photolithography, screen printing, shadow masking and the like. The correct red, green and blue color information can be obtained by differentiation of the signals (in the read-out circuit) from the three sub-pixels, 12R, 12G and 12B, as demonstrated in the examples of this invention. An optically uniform material is used as the substrate which is transparent in the visible and opaque in UV.

Detailed Description Text (25):
The color selection can also be achieved by combining the device structure shown in FIG. 4 with that shown in FIG. 5. For instance, with the photosensing material in the photodiode defining part of the spectral response, the optical filter placed in front fine-tunes the response desired. Example 15 utilizes this approach for a

photosensor simulating the response of the human eye.

Detailed Description Text (27):
The photoactive layer 12 in the voltage-switchable photodiodes is made of a thin sheet of organic semiconducting material. The active layer can comprise one or more semiconducting, conjugated polymers, alone or in combination with non-conjugated materials, one or more organic molecules, or oligomers. The active layer can be a blend of two or more conjugated polymers with similar or different electron affinities and different electronic energy gaps. The active layer can be a blend of two or more organic molecules with similar or different electron affinities and different electronic energy gaps. The active layer can be a blend of conjugated polymers and organic molecules with similar or different electron affinities and different energy gaps. The latter offers specific advantages in that the different electron affinities of the components can lead to photoinduced charge transfer and charge separation; a phenomenon which enhances the photosensitivity [N. S. Sariciftci and A. J. Heeger, U.S. Pat. No. 5,333,183 (Jul. 19, 1994); N. S. Sariciftci and A. J. Heeger, U.S. Pat. No. 5,454,880 (Oct. 3, 1995); N. S. Sariciftci, L. Smilowitz, A. J. Heeger and F. Wudl, Science 258, 1474 (1992); L. Smilowitz, N. S. Sariciftci, R. Wu, C. Gettinger, A. J. Heeger and F. Wudl, Phys. Rev. B 47, 13835 (1993); N. S. Sariciftci and A. J. Heeger, Intern. J. Mod. Phys. B 8, 237 (1994)]. The active layer can also be a series of heterojunctions utilizing layers of organic materials or blends as indicated above.

Detailed Description Text (52):
As shown in FIGS. 1 and 2, the organic photodiodes of this invention are constructed in an M--S--M structure, in which the organic photoactive layer is bounded on two sides with conductive contact electrodes. In the configuration shown in FIG. 1, a transparent substrate 14 and a transparent electrode 11 are used as one contact electrode. Indium-tin-oxides ("ITO") can be used as the electrode 11. Other transparent electrode materials include aluminum doped zinc oxides ("AZO"), aluminum doped tin-oxides ("ATO"), tin-oxides and the like. These conducting coatings are made of doped metal-oxide compounds which are transparent from near UV to mid-infrared.

Detailed Description Text (55):
A thin semitransparent layer of metals (such as Au, Ag, Al, In etc.) can also be used as the electrode 11 in FIG. 1 and 13 in FIG. 2. Typical thicknesses for this semitransparent metal electrode are in the range of 50-1000 .ANG., with optical transmittance between 80% and 1%. A proper dielectric coating (often in the form of multilayer dielectric stacks) can enhance the transparency in the spectral range of interest [For examples, see S. M. Sze, Physics of Semiconductor Devices (John Wiley & Sons, New York, 1981) Chapter 13].

Detailed Description Text (58):
The "back" electrode 13 in FIG. 1 (and 11 in FIG. 2) is typically made of a metal, such as Ca, Sm, Y, Mg, Al, In, Cu, Ag, Au and so on. Metal alloys can also be used as the electrode materials. These metal electrodes can be fabricated by, for example, thermal evaporation, electron beam evaporation, sputtering, chemical vapor deposition, melting process or other technologies. The thickness of the electrode 13 in FIG. 1 (and 11 in FIG. 2) is not critical and can be from hundreds of .ANG.ngstroms to hundreds of microns or thicker. The thickness can be controlled to achieve a desired surface conductivity.

Detailed Description Text (59):
When desired, for example, for a photodiode with detectivity on both front and back side, the transparent and semi-transparent materials described above can also be used as the "back" electrode 13 in FIG. 1 (and 11 in FIG. 2).

Detailed Description Text (64):
One type of application is a photosensor with selected spectral response, for example, from 500 to 600 nm. One effective approach is taking an organic photodiode with low energy cut-off at 600 nm (for example, a photodiode made with MEH-PPV), and placing a long-wavelength, low pass optical filter (with cut-off at 500 nm) in front. The spectral response of semiconducting oligomers and polymers can be controlled by modifying the side chain or main chain structures. For example, by

varying the side chain of the PPV system, the optical gap can be tuned from 500 nm to 700 nm. An alternative approach to achieving bandpass selection is to place a bandpass optical filter in front of an organic photodiode with wider spectral response.

Detailed Description Text (66):
A simple but effective approach to full-color image sensors is sketched in FIG. 4. In this approach, the photodiode matrix is made of single sheet of active layer without patterning. The active areas are defined by the row and column electrodes. The spectral response of these organic photodiodes should cover the entire visible region (400-700 nm). Color selection is achieved by the color filter panel in front of the transparent electrodes. There arc many organic materials or blends with photoresponse covering the entire visible spectrum. Examples include PT derivatives such as "P3AT" [G. Yu, et al., Phys. Rev. B42, 3004 (1990), "POPT", poly(3-(4-octylphenyl)thiophene) [M. R. Andersson, D. Selese, H. Jarvinen, T. Hjertberg, O. Inganas, O. Wennerstrom and J. E. Osterholm, Macromolecules 27, 6503 (1994)], PTV and its derivatives and the like.

Detailed Description Text (71):
The invention of voltage-switchable organic photodiodes provides the foundation for fabrication of large size, low cost 2D image sensors based on x-y addressable passive diode matrices. This type of photodiode shows high photosensitivity (typically in the range of 30-300 mA/W), quantum efficiency (even over 100% electrons/photon at given reverse biases) and virtually zero response at a bias voltage close to the built-in potential. Thus, a row of pixels in a column-row matrix of such photodiodes can be selected by setting the selected row at reverse bias and the pixels on the other row biased at a voltage close to the built-in potential. In this way, crosstalk from pixels in different rows is eliminated. The image information at the pixels in the selected row can be read-out correctly in both the serial mode or the parallel mode. The information on the pixels in the other rows can be read-out in sequence or in selected fashion by setting the row of interest to reverse bias. The x-y addressable organic photodiode matrices provide a new type of 2D image sensor which can be made in large size, with low fabrication cost, onto substrates in desired shape or flexible, and hybridizable with other optical or electronic devices.

Detailed Description Text (74):
(ii) 2D, x-y addressable, passive image sensors fabricated with the organic photodiodes with switchable photosensitivity. Crosstalk-free read-out can be achieved with these passive image sensors by means of proper electronic pulse sequences.

Detailed Description Text (79):
Voltage-switchable photodiodes were fabricated by evaporating a 5000.ANG. calcium contact (13) on the front of a thin MEH-PPV film 12 which was spin-cast from solution onto a ITO/glass substrate 14. The glass substrate had been previously partially coated with a contact layer 11 of indium-tin-oxide (ITO). The active area of each device was 0.1 cm.sup.2. The MEH-PPV film was cast from a 0.5% (10 mg/2 ml) xylene solution at room temperature. Details on the synthesis of MEH-PPV can be found in literature [F. Wudl, P. M. Allemand, G. Srdanov., Z. Ni, and D. McBranch, in Materials for Nonlinear Optics:Chemical Perspectives, Ed. S. R. Marder, J. E. Sohn and G. D. Stucky (American Chemical Society, Washington, D.C., 1991) p. 683]. The thickness of the active layer was adjusted by varying the concentration of the solution, by varying the spin speed of the spinner head and by applying multiple coating layers.

Detailed Description Text (83):
Other metals such as Al, In, Cu, Ag and the like were also used for the counterelectrode 13 (see FIG. 1) which is the cathode in these devices. Similar photosensitivities to that shown in FIG. 5 were observed in all these devices. The off-state voltage which balanced off the internal potential of the photodiode varied with the work function of the metal; the off-state voltage is determined by the work function difference between the metal cathode and the ITO anode. Table 1 lists the off-state voltage found for MEH-PPV photodiodes with several metal electrodes.

Detailed Description Text (86):
This example demonstrates that high photosensitivity can be achieved with MEH-PPV organic photodiodes under reverse bias. The desired photosensitivity can be achieved at a given reverse bias. The photosensitivity can be switched off at a proper bias voltage which is dependent on the electrode materials selected. As shown in Table 1, air stable metals with work functions over 4 V can be used for the electrodes in organic photodiodes. This example also demostrates that the off-state voltage is determined by the work function of the electrode close to the interface area. This example also demonstrates the broad dynamic range of the polymer photodiodes, a dynamic range which is sufficient to enable image detection with multi-grey levels.

Detailed Description Text (89):
This example demonstrates that the voltage-switchable organic photodiodes can be fabricated in a thin structure, in flexible form, or in a desired shape to meet the special needs in specific applications.

Detailed Description Text (95):
This example demonstrates that conducting polymer materials can be used as the transparent electrodes of the photodiodes and image sensors. These plastic electrode materials provide the opportunity to fabricate organic photosensors in flexible or foldable forms. This example also demonstrates that the polymer electrode can be inserted between a metal-oxide transparent electrode (such as ITO) and the active layer to modify the interfacial properties and the device performance.

Detailed Description Text (105):
Voltage-switchable photodiodes were fabricated in the structure of ITO/MEH-PPV:PCBM/metal, similar to that shown in FIG. 1. The PCBM (a C.sub.60 derivative) served as an acceptor in a donor-acceptor pair with the MEH-PPV acting as donor. The active area of these devices was .about.0.1 cm.sup.2. The blend solution was prepared by mixing 0.8% MEH-PPV and 2% PCBM/xylene solutions with 2:1 weight ratio. The solution was clear, uniform, and was processable at room temperature. Solutions were stored in a N.sub.2 box for over 1.5 years and no aggregation or phase separation were observed. The active layer was spin-cast from the solution at 1000-2000 rpm. Typical film thicknesses were in the range of 1000.about.2000 .ANG.. Ca, Al, Ag, Cu, and Au were used as the counter electrode 13. In each case, the film was deposited by vacuum evaporation with thickness of 1000-5000 .ANG.. In another experiment, the concentration of the acceptor PCBM was varied from 0 to 1:1 molecular ratio. Higher on state photosensitivity and lower on-state operation voltage were observed in devices with higher concentrations.

Detailed Description Text (106):
FIG. 8 shows the I-V characteristics of an ITO/MEH-PPV:PCBCR/Al device in the dark and under light illumination. The thickness of the blend film was .about.2000 .ANG.. The dark current saturated at .about.1nA/cm.sup.2 below 3 V and then increased superlinearly at high bias voltages (>E.sub.g /e). Zener tunneling can account for this effect. The photocurrent was measured. The photocurrent at 0.65 V was .about.1.times.10.sup.-7 A/cm.sup.2, increasing to 5.times.10.sup.-4 A/cm.sup.2 at -10 V bias. The on-off ratio was .about.500. Devices with thinner blend films showed improved photosensitivity and higher on-off ratio. Similar photosensitivity was also observed in devices fabricated with other metals or metal alloys as the counter electrodes. These included Ag, Cu, Ca, Sm, Pb, Mg, LiAl, MgAg, BaAl.

Detailed Description Text (108):
This example demonstrates that the photosensitivity can be further improved by blending a donor polymer with a molecular acceptor such as C.sub.60, PCBM, PCBCR. High photosensitivity can be achieved at relatively low bias and low field (.about.10.sup.5 V/cm). This example also demonstrates that the photosensitivity can be switched to nearly zero when bias the device at a voltage balancing the internal built-in potential (.about.0.65 V for Al cathode). The data in this example show that, due to its low dark current level, the polymer photodiode can be used to detect weak light down to intensity level of tens of nW/cm.sup.2. Thus, the polymer photodiodes have a dynamic range spanning more than six orders of magnitude, from nW/cm.sup.2 to 100 mW/cm.sup.2.

Detailed Description Text (110):

Devices similar to those of Example 6 were fabricated with glass/ITO and PET/ITO substrates in 4.5 cm.times.4 cm (18 Cm.sup.2) and in 3.8 cm.times.6.4 cm (24.3 cm.sup.2) using a fabrication process similar to that of Example 6. I-V characteristics similar to that shown in FIG. 8 were observed. The photodiodes made with flexible PET substrates were bent into circular shapes any without change in their photosensitivity.

Detailed Description Text (117):
Examples 8 and 9 demonstrate that the active layer of the voltage-switchable photodiodes can be organic molecules arranged in bilayer or multilayer structures, a blend of organic molecules, or a blend of conjugated polymers, in addition to a polymer/molecule blend as demonstrated in example 6. The data in these examples along with that in the Example 1 also demonstrate that, for a given cathode such as Ca, the off-state voltage varies with the electronic structure of the active material.

Detailed Description Text (119):
Voltage-switchable organic photodiodes was fabricated with P3OT as the active layer in an ITO/P3OT/Au structure. The I-V characteristics in the dark and under light illumination are shown in FIG. 9. Since the work function of Au is higher than ITO, the Au electrode serves as the anode in these devices. Positive bias was defined such that a higher potential was applied to Au electrode. Light was incident from the cathode (ITO) electrode. In this experiment, a He-Ne laser at 633 nm was used as the illumination source with a photon density of 10 mW/cm.sup.2.

Detailed Description Text (120):
The built-in potential in this photodiode was reduced to nearly zero volts. Thus, the off-state of the photodiode was shifted to close to zero volts. The photocurrent at -12 V was 1 mA/cm.sup.2, which was 10.sup.4 times higher than that at zero bias. Values of the ratio I.sub.ph (-12V)/I.sub.ph (0) in excess of 1.5.times.10.sup.5 have been realized in similar devices. The photosensitivity at 633 nm was .about.100 mA/W, corresponding to a quantum efficiency of .about.20 % ph/el. The dark current in the test range was below 5.times.10.sup.-7 A/cm.sup.2. The photocurrrent/dark current ratio was greater than 1000 over a broad bias range (-4.about.-12 V).

Detailed Description Text (121):
This example demonstrates that the off-state of the photodiode can be varied by proper selection of the active material and the electrode materials. This voltage can be set to a voltage close to zero volts. A photodiode matrix fabricated with this type of photodiode can be driven by pulse trains with mono-polarity, thus simplifying the driving circuitry. The large on/off switching ratio and the large photocurrent/darkcurrent ratio permit the photodiodes to be used in the fabrication of x-y addressable passive matrices with high pixel density and with multiple-gray levels.

Detailed Description Text (123):
Two-dimensional, photodiode matrices were fabricated with seven rows and 40 columns. Pixel size was 0.7 mm.times.0.7 mm. The space between the row electrodes and the column electrodes was 1.27 mm (0.05"). The total active area was .about.2".times.0.35". Typical I-V characteristics from a pixel are shown in FIG. 10. White light from a fluorescent lamp on the ceiling of the lab was used as the illumination source with intensity of .about.tens of .mu.W/cm.sup.2. This is much weaker than the light intensity used in document scanners.

Detailed Description Text (124):
This example demonstrates that pixelated photodiode matrices can be fabricated without shorts and without crosstalk. This example also demonstrates that these devices can be used for applications with light intensities equal to or much less than a microwatt/cm.sup.2. Thus, polymer photodiode matrices are practical for image applications under relatively weak light conditions.

Detailed Description Text (126):
A scanning scheme for the photodiode matrix was developed (see FIG. 11). Due to the strong voltage dependence of the photosensitivity, a column of pixels in the 2D photodiode matrix could be selected and turned on with proper voltage bias, leaving

the pixels in the adjacent rows insensitive to the incident light. Under such operation, the physical M row, N column 2D matrix is reduced to N isolated M element linear diode arrays which are free from crosstalk between columns. This is reminiscent of the concept that is used in solving a 2D integral by dimension reduction, .intg.f(x,y)dxdy=.intg.g(x)dx .intg.h(y)dy. With Such 2D, passive photodiode arrays, an image can be read out with a pulse train scanning through each column of the matrix.

Detailed Description Text (127):
FIG. 11 shows a instantaneous "snap-shot" of the voltage distribution in a 7.times.40 photodiode matrix. At a specific time t, all the pixels were biased at +0.7 V except the pixels in column 1. The pixels in column 1 were all biased at -10 V so as to achieve high photosensitivity (ten-hundreds of mA/Watt). The information at each of the pixels in column 1 was read-out in both parallel (with N channel converting circuits and A/D converters) or serial (with N channel analog switches) sequences. Pixels in other columns were selected by switching the column bias from +0.7 V to -10 V in sequence. A digital shift register was used for the column selection.

Detailed Description Text (128):
To simplify the driver circuit, it was preferable that the photosensor can be switched on and off between 0 V and a reverse bias voltage (-2 to -10 V). Such a mono-polarity, voltage-switchable photodiode was demonstrated with ITO/P3OT/Au, as shown in Example 10.

Detailed Description Text (130):
An image of multi-gray levels was selected, the image was scanned with the 7.times.40 photodiode matrix following the scanning scheme discussed in Example 12. The original image and the readout image were recorded photographically. The readout image reproduced the original image with excellent fidelity.

Detailed Description Text (131):
This example demonstrates that the voltage-switchable photodiodes can be used as the pixel elements of a column-row matrix (as shown in FIG. 3). The photodiodes at each pixel can be addressed effectively from the column and row electrodes. Image information with multiple gray-levels can be read-out without distortion.

Detailed Description Text (133):
Devices similar to those of Example 10 were fabricated and their spectral response was measured at a reverse bias of -15V. The data are shown in FIG. 12. In contrast to the significant sensitivity decrease at short wavelength in conventional inorganic photodiodes, the P3OT photodiodes exhibited relatively flat response for wavelengths shorter than 630 nm; the apparent decrease in sensitivity below 350 nm was mainly due to the transmission cut-off of the ITO coated glass substrate. For -15 V bias, the sensitivity at 540 nm reached 0.35 A/W (a quantum yield of .about.80% el/ph), the same value as obtained with UV-enhanced Si diodes. Similar photosensitivity values persisted into the UV region below 400 nm. In some devices, quantum efficiency of over 100% el/ph (140.about.180% el/ph) was observed under reverse bias.

Detailed Description Text (137):
Voltage-switchable photodiodes were fabricated to achieve a response similar to the visual response of the human eye, V(.lambda.). The devices were fabricated by coating a long-wavelength-pass filter onto the front panel of the glass substrates of devices, similar to those shown in Example 15. The coating material in this example was a layer of PPV which was converted from its precursor film at 230.degree. C. The photoresponses of the devices with and without the filter are shown in FIG. 13A. The visual response of the human eye, V(.lambda.) (see FIG. 13B), and the transmittance of the PPV optical filter are shown for comparison. The photoresponse of the P3OT diode closely coincided with V(.lambda.) for wavelengths longer than 560 nm, while the optical transmittance of the PPV filter followed V(.lambda.) over a broad range between 450 nm and 550 nm.

Detailed Description Text (140):
Solar-blind UV detectors were fabricated with polyblend MEH-PPV:C.sub.60. ITO and Al

were used as anode and cathode materials. The devices were fabricated on an UV bandpass filter purchased from Melles Griot Inc. (product No. 03 FCG 177). FIG. 14 shows the spectral response of the UV detector operating at -2 V. The spectral response of the MEH-PPV:C.sub.60 photodiode on ITO/glass substrate and the response of an UV-enhanced Si photodiode are plotted for comparison. The data show that the polymer UV detector was sensitive to UV radiation between 300-400 nm with photosensitivity of .about.150 mA/W, comparable to that of UV-enhanced silicon photodiode. The data also show that the photoresponse of the MEH-PPV photodiode was suppressed (over 10.sup.3 times) by the optical bandpass filter.

Detailed Description Text (141):
This example demonstrates that high sensitivity, solar-blind UV detectors can be fabricated by integrating voltage-switchable organic photodiodes with UV pass optical filters.

Detailed Description Text (143):
Example 14 was repeated except that the active layer was a thin PTV layer. The spectral response of a PTV photodiode is shown in FIG. 15A, which covers the range from 300 to 700 nm; i.e., spanning the entire visible range. Selected color detection was achieved by inserting a bandpass filter or a long wavelength filter in front of the detectors. FIG. 15B shows the responses of a blue-color pixel, a green-color pixel and a red-color pixel made with a panel of color filters and an array of PTV photodiodes. The transmittance of the corresponding R,G,B color filters is shown in FIG. 15C.

Detailed Description Text (144):
This example demonstrates that by coupling the polymer image sensor with a panel of color filters, R,G,B color recognition can be achieved with a panel of polymer photodiode matrix with response covering entire visible spectrum.

Detailed Description Text (146):
Red, green and blue (R,G,B) color detection were achieved following the approach shown in FIG. 5. The materials used for the active layers were PPV with a long wavelength cut-off at 500 nm; poly(dihexyloxy phenylene vinylene), "PDHPV", with a long wavelength cut-off at 600 nm; and PTV with long wavelength cut-off at 700 nm. Films were cast from solutions in their precursor forms with thickness between 1000 .ANG.-3000 .ANG.. Conversion to the conjugated forms was carried out at temperatures between 150-230.degree. C. The conjugated films formed in this way were insoluble to organic solvents. Thus, patterning of these materials on a single substrate in dot or strip shapes can be achieved with standard photolithography, screen printing and the like. The normalized photoresponse of these photodiodes is shown in FIG. 16A. An ITO/glass substrate was used in this experiment which is optically transparent in visible and opaque in UV.

Detailed Description Text (147):
Red and green selective color detection were achieved by differentiation of the signals from these photodiodes (this operation can be done in the read-out circuit). The differential responses of these photodiodes are shown in FIG. 16B. Red color detection (with response between 600-700 nm) was achieved by subtracting the signal from the PTV photodiode from the signal from the PDHPV photodiode. Green color detection (with response between 500-600 nm) was achieved by subtraction of the PDHPV signal from the PPV signal. The blue color detection was obtained by PPV photodiode directly.

Detailed Description Text (150):
Voltage-switchable photodiodes were fabricated with the conjugated polymer poly(p-phenyl vinylene), PPV as photoactive material. The PPV films were spin-cast onto ITO substrates from a nonconjugated precursor solution and then converted to conjugated form by heating at 200-230.degree. C. for 3 hours. Al was used as the back electrode. The active area was .about.0.15 cm.sup.2. The I-V characteristics of this photodiode in the dark and under illumination are shown in FIG. 17. The photocurrent/darkcurrent ratio is in the range of 10.sup.4 for white light illumination of a few mW/cm.sub.2. Relatively low dark current was observed in forward bias as compared to that observed in photodiodes of, for example, in Example 1. This allows photodetection in both forward bias and reverse bias as shown in FIG.

17. The photosensitivity can be switched on and off by varying the external biasing voltage. For example, under white (or UV) light illumination, the photocurtent at +5V or -5V is 2000 times higher than that at +0.95V (or 0.3V).

Detailed Description Text (151):
This example demonstrates that the photodiode can be switched on by applying a forward bias (beyond the vicinity of the voltage corresponding the off state) or a reverse bias. Photodiodes operable in both switch polarities are useful in certain circuit designs and applications.

Detailed Description Text (153):
Voltage-switchable photodetectors were fabricated which had a heterojunction structure as their active layers. they had an ITO/donor layer/acceptor layer/metal structure. The materials used for the donor layer were MEH-PPV and PPV. The material used for the acceptor layer were C.sub.60, laid down by physical vapor deposition and PCBM and PCBCR laid down by drop casting or spin casting. A data set for a MEH-PPV/C.sub.60 photodiode is shown in FIG. 18.

Detailed Description Text (158):
FIG. 19 shows the photo- and dark currents from a P3HT device with 3150 .ANG. film thickness. The data were taken with white light illumination of 8 mW/cm.sup.2 (between 400 nm and 700 nm) and with monochromatic light (600 nm at 1.1 mW/cm.sup.2). In the dark, the reverse current saturates at low field region and then increases with the biasing voltage, to .about.2.times.10.sup.-5 mA/cm.sup.2 at -25 V bias. The forward current increases exponentially under forward bias (for voltages>1 V), reaching .about.1 mA/cm.sup.2 at 3 V bias. The exponential forward current covers more than 5 orders of magnitude in the voltage range from 1-2 V. The rectification ratio at 2 V is over 10.sup.4. Strong photosensitivity was observed in reverse bias. The photocurrent at -25 V reaches 5.33 mA/cm.sup.2 under 8 mW/cm.sup.2, white light illumination. This number corresponds to a photoresponsivity of in excess of 0.5 A/W, corresponding to a quantum efficiency larger than 100% electrons/photon. A high I.sub.ph (V.sub.on)/I.sub.ph (V.sub.off) switching ratio was also achieved in this devices: under 8 mW/cm.sup.2, I.sub.ph (-25 V)/I.sub.ph (0.5) is .about.4.times.10.sup.7. This switching ratio is equal to or even better than the switching ratio of TFT-based photosensors made with inorganic semiconductors (10.sup.4 -10.sup.7). These organic photodiodes also exhibit a high I.sub.ph (V)/l.sub.dark (V) ratio. The I.sub.ph /I.sub.dark at -25 V is .about.4.times.10.sup.5 for 8 mW/cm.sup.2 white light illumination, which implies that more than 18 bits (2.6.times.10.sup.5) gray levels can be resolved for image applications.

Detailed Description Text (159):
The high switching ratio implies that for an x-y addressable 2D photodiode matrix of 400.times.390 pixels (refer to FIG. 3 of the 2D patent), more than 256 gray levels can be resolved. Adopting quad-matrix design (four sub-matrices arranged in each quadrants), more than 1000.times.625 pixels are possible with the same resolution. This pixel density is even better than the SVGA standard. The drive circuit for these photodiode matrices is simplified; digital shift registers and BCD digital decoders can be used.

Detailed Description Text (160):
These photosensors can also be used to fabricate high pixel density linear photodiode arrays. Since only the pixel at the node contributes to the pixel dark current, there is no restriction on the number of pixels. Hence, the gray level of the sensor array can be as high as 2.sup.18 =3.times.10.sup.5. These results suggest that the organic photosensor arrays constructed from ITO/P3HT/Al can be used for high quality image sensing. Moreover, the driver circuits for column selection are simplified considerably and digital shift registers or digital decoders can be used directly.

Detailed Description Text (161):
This example demonstrates an organic photosensor with high switching ratio and high I.sub.ph /I.sub.dark ratio. The photosensitivity of such photosensors covers the entire visible spectral range. These sensors arc especially suitable for constructing linear photodiode arrays and 2D photodiode matrices for high quality

image sensing applications.

Detailed Description Text (163):
Linear photodiode arrays were fabricated with 102 sensing elements, each made with P3OT as the semiconducting polymer. Two typical structures of the photodiode arrays are shown in FIG. 20A and FIG. 20B. The pixel size was .about.0.635 mm.times.0.635 mm. The length of the total sensing area was .about.2.5", longer than any linear photodiode array commercially available. A full-color linear scanner was constructed with a sensing circuit shown in FIG. 21, no analog switching elements (such as field effect transistors) were used in this driver. The read out circuit was digitized into 8 bit with 256 gray levels. Red, green and blue color filters were mounted on a panel and was switched in front of the linear diode array when collecting the corresponding images. The linear photodiode array was mounted on a computer controlled translation stage for the image scanning. A full-color image taken with this scanner is shown in FIG. 22D. It was recovered by a superposition of the red, green and blue color images (FIGS. 22(a,b,c)) taken separately. The image quality was similar to that achieved with a commercial color scanner in the same pixel format (40 dpi) with so-called "multi-million (256.sup.3) colors" format.

Detailed Description Text (164):
Linear photodiode arrays were also fabricated in 40 dpi and 50 dpi forms with total pixels of 200 and 240. The total sensing length is close to 5". The arrays were used for image sensing experiments. Large size (5".times.11"), high quality (8-10 bit), full-color image sensing was demonstrated.

Detailed Description Text (165):
This example demonstrates that organic photodiode arrays can be used for large size image sensing applications with full-color capability and with multiple gray levels.

Detailed Description Text (167):
The linear photodiode arrays demonstrated in Example 22 were also used for visible-blind UV sensing. In this experiment, a visible blocking, UV pass filter was placed in front of the array. The UV image generated with UV ink was projected onto the sensor. The UV image was read out with the organic photodiode array.

Detailed Description Text (170):
Linear photodiode arrays were fabricated in the same configuration as that of Example 22 (1.times.102 pixels, 40 pixels/in). One of the sensor arrays was used as an optical beam analyzer to test the optical field distribution a laser beam. The intensity distribution of the testing optical field is shown in FIG. 23. This example demonstrates that the polymer photodiode array can be used to detect spatial distribution of an optical beam. This function is of broad applications in industrial automation.

Detailed Description Text (172):
Another 1.times.102 linear photodiode array was fabricated on PET substrate (7 mil in thickness). The flexible sensor array was arranged in a semicircular shape. A point light source from a green light emitting diode was placed at the center of the circle, and the angular distribution of the light intensity was tested with the curved sensor array. The result is shown in FIG. 24.

Detailed Description Text (173):
This example demonstrates that the polymer linear photodiode arrays can be fabricated onto flexible substrates or on curved substrates to fit into an optical apparatus or to probe the spatial distribution of an optical field. The fabrication process and the thin film architecture of the polymer photodiode arrays also allow them to be integrated with electronic drivers on a silicon wafer or integrated with an adapted optical component.

Detailed Description Text (175):
A P3OT photodiode array was used as the detector of an UV-visible spectrometer for transmission measurement. The setup is shown in FIG. 25. A transmission spectrum of a thin film of poly(p-phenylene vinylene), PPV, was measured with the polymer linear photodiode arrays. The result is shown in FIG. 26.

Detailed Description Text (176):
This example demonstrates that the organic photodiode arrays can be used for spectrographic applications.

Detailed Description Text (178):
Voltage-switchable photosensor were fabricated in a metal(1)/P3HT/metal(2) sandwich structure. In one case, metal(1) was Au and metal(2) was Al. The thickness of the Au layer was varied from 20nm to 80 nm and the optical transmission of the Au layer was varied from 50% to .about.1%. The optical reflection of the Au layer varies correspondingly. The thickness of the Al layer was more than 100 nm, so that its reflectance was almost 100%. Such a metal/organic layer/metal structure forms an optical microcavity (optical etalon) device in the spectral region where the optical absorption of the organic layer is relatively low. Such a microcavity structure possesses optical resonance at selected wavelengths. The center wavelength and the bandwidth of the sensing profile can be adjusted by changing the reflection of the metal electrode, by the absorption coefficient, the dielectric constant and the thickness of the organic layer. FIG. 27 shows the spectral response of such device.

Detailed Description Text (179):
Microcavity devices were also made in the "reverse" structure similar to that shown in FIG. 2; i.e., with light incident onto the free surface electrode (13). The devices were made in both configurations: glass/Au(100 nm)/MEH-PPV/Ag(50nm) and glass/Ag(100 nm)/MEH-PPV/Au(50nm). In these devices, Au acts as the anode and Ag as the cathode. Selective spectral response was observed in both structures. These results demonstrate the flexibility of fabricating the wavelength selective sensors on either transparent substrates or opaque substrates. These results also demonstrate that the devices can be designed so that the light is incident onto either the anode or cathode electrode.

Detailed Description Text (181):
This example also demonstrates that the organic photosensors can be constructed with wavelength selectivity of narrow bandwidth. Building such a photodiode array or 2D matrix in which each pixel has a different sensing profile forms a flat-panel spectrometer. These kinds of devices have great potential for image sensing, spectrographic, biophysical and biomedical applications.

Detailed Description Paragraph Table (1):
TABLE 1 Off-state voltage in ITO/MEH-PPV/metal photodiodes Metal cathode Ca Sm Yb Al In Ag Cu V.sub.off (V) 1.5 1.5 1.5 1.1 0.9 0.7 0.4

CLAIMS:

1. A switchable organic photodetector capable of producing a photocurrent in response to light impinging thereupon comprising a photodiode and a variable voltage source, said photodiode having a built-in potential and comprising:

a first electrode;

a photoactive organic layer disposed on said first electrode; and

a second electrode disposed on said photoactive organic layer; and said voltage source adapted to selectively apply a switching voltage across said first electrode and said second electrode, said switching voltage imparting a photosensitivity above 1 mA/W at a preselected operating bias and near-zero photosensitivity at a cut-off bias substantially equivalent in magnitude to said built-in potential.

2. A photodiode detector of claim 1 wherein the operating bias is an operating reverse bias.

3. A photodiode detector of claim 1 wherein the operating bias is an operating forward bias.

4. A read-out circuit comprising an organic photodiode detector of claim 1 and means for detecting the photocurrent, wherein the operating bias is in the range of 1-15 V

and represents an ON state of the photodiode, said detector having a photosensitivity above 1 mA/Watt in said ON state, and wherein the cut-off bias represents an OFF state of the photodiode equivalent to zero photoresponse at an output of the read-out circuit.

6. A photodiode array comprising a plurality of photodiode detectors of claim 1 said detectors having their photodiodes arranged in an array, each of said photodiodes being selectively addressable as a pixel of said array.

7. The photodiode array of claim 6, wherein said array comprises at least one row of photodiodes and at least one column of photodiodes, each row having associated therewith a common anode, each column having associated therewith a common cathode, the first electrode of each photodiode of a row being connected to said common anode, the second electrode of each photodiode of a column being connected to said common cathode, said voltage source adapted to apply said switching voltage across at least one common anode and at least one common cathode to thereby selectively activate at least one pixel of said array.

8. The photodiode array of claim 7, comprising means for applying said switching voltage across a plurality of common anodes and at least one common cathode to thereby selectively activate at least one column of pixels of said array.

9. The photodiode array of claim 7, comprising means for applying said switching voltage across a plurality of common cathodes and at least one common anode to thereby selectively activate at least one row of pixels of said array.

10. The photodiode array of claim 7, additionally comprising a coating of black matrix in the space between the pixels.

13. A scannable array of voltage-switchable organic photodiodes each having a built-in potential and a predetermined photosensitivity range, said array comprising:

a support substrate;

a first electrode layer comprising at least one linear electrode disposed on said support substrate along a first direction;

a photoactive organic layer disposed on said linear electrode;

a second electrode layer comprising a plurality of linear electrodes disposed on said photoactive layer along a second direction transverse to said first direction; and

a voltage source adapted to apply a switching voltage across at least one electrode of said first electrode layer and at least one electrode of said second electrode layer, said switching voltage thereby imparting to at least one selected photodiode a photosensitivity above 1 mA/W at an operating reverse bias and near-zero photosensitivity at a cut-off bias substantially equivalent in magnitude to said built-in potential.

17. A method of selectively detecting light incident on an array of voltage-switchable organic photodiode detectors, said array comprising a plurality of photodiodes arranged in a row and column matrix, each photodiode having a built in potential and adapted to generate an output in response to incident radiation, each photodiode comprising a first electrode, a photoactive organic layer disposed on said first electrode, and a second electrode disposed on said photoactive layer, the first electrode of each photodiode in a row being electrically connected to a common anode, the second electrode of each photodiode in a column being electrically connected to a common cathode, said method comprising:

sequentially activating a selected column of photodiodes by;

applying an operating bias voltage across the common cathode associated with said selected column and all the common anodes, said operating bias voltage imparting to

each photodiode of the selected column a photosensitivity above 1 mA/W;

applying a cut-off voltage across remaining cathodes and all the anodes, said cut-off voltage being equivalent in magnitude to said built-in potential and imparting to the photodiodes of all columns other than the selected column near-zero photosensitivity; and

sequentially reading out the generated output of the selected column of photodiodes.

18. A method of selectively detecting light incident on an array of voltage-switchable organic photodiode detectors, said array comprising a plurality of photodiodes arranged in a row and column matrix, each photodiode having a built in potential and adapted to generate an output in response to incident radiation, each photodiode comprising a first electrode, a photoactive organic layer disposed on said first electrode, and a second electrode disposed on said photoactive layer, the first electrode of each photodiode in a row being electrically connected to a common anode, the second electrode of each photodiode in a column being electrically connected to a common cathode, said method comprising:

sequentially activating a selected row of photodiodes by;

applying an operating bias voltage across the common anode associated with said selected row and all the common cathodes, said operating bias voltage imparting to each photodiode of the selected row a photosensitivity above 1 mA/W;

applying a cut-off voltage across remaining anodes and all the cathodes, said cut-off voltage being equivalent in magnitude to said built-in potential and imparting to the photodiodes of all rows other than the selected row near-zero photosensitivity; and

sequentially reading out the generated output of the selected row of photodiodes.

19. organic photodiode detector comprising a photodiode and a voltage source, said photodiode having built-in potential and a prescribed photosensitivity range in response to incident radiation, said photodiode comprising:

a first electrode;

a photoactive organic layer disposed on said first electrode;

a second electrode disposed on said photoactive organic layer; and said voltage source adapted to apply an operating biasing voltage across said first electrode and said second electrode, said biasing voltage operating to vary said prescribed photosensitivity range, wherein the photosensitivity of said photodiode is above 1 mA/W at an operating bias of said voltage source and is at a near-zero level at a cut-off bias substantially equivalent in magnitude to said built-in potential, said voltage source being switchable between said operating bias and said cut-off bias.

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DOCUMENT-IDENTIFIER: US 6392617 B1
TITLE: Active matrix light emitting diode display

Abstract Text (1):
An active matrix pixel within an active matrix display includes a photodiode that is optically connected to a light emitting diode within the pixel in order to detect a portion of the luminous flux that is generated by the light emitting diode. The photodiode discharges excess charge within the pixel in response to the detected portion of luminous flux. Once the excess charge is discharged, the light emitting diode stops emitting light. In an embodiment, the gate of a drive transistor is controlled by the charge on a storage node. If the charge on the storage node sets a voltage that exceeds the threshold voltage of the drive transistor then the drive transistor conducts. The amount of charge on the storage node above that which is needed to set the threshold voltage is referred to as the excess charge.

Brief Summary Text (4):
Arrays of organic light emitting diodes (OLEDs) are being utilized to create two-dimensional flat panel displays. As compared to conventional light emitting diodes (LEDs), which are made of compound semiconductors, the low cost and ease of patterning OLEDs makes compact, high resolution arrays practical. OLEDs can be adapted to create either monochrome or color displays and the OLEDs may be formed on transparent or semiconductor substrates.

Brief Summary Text (10):
As described above, in order to obtain the desired luminous flux from the OLED 212 of FIG. 2, the voltage on the data line 204 is adjusted to control the current through the drive transistor 208. Unfortunately, current flow through the drive transistor also depends on characteristics of the drive transistor, such as its threshold voltage and transconductance. Large arrays of drive transistors, as required to make a high-resolution display, exhibit variations in threshold voltage and transconductance that often cause the drive currents of the OLEDs to differ for identical control voltages, which in turn causes a display to appear non-uniform. In addition, different OLEDs emit different intensities of light even when driven with identical currents. Furthermore, the light intensity for a specified drive current drops as an OLED ages and different OLEDs can degrade at different rates, again causing a display to appear non-uniform.

Brief Summary Text (13):
As described above the intensity of light generated by an OLED is influenced by the voltage supplied to the storage node and by characteristics of the drive transistors and OLEDs, which can vary from pixel to pixel. The differences in the characteristics of the pixels can produce non-uniform light intensities. In addition, as OLEDs age, the degree of non-uniformity may change. As a result, what is needed is a system and method for individually driving each pixel in an active matrix array that provides uniform luminous flux while meeting the size limitations of active matrix displays.

Brief Summary Text (15):
An active matrix pixel within an active matrix display includes a photodiode that is optically connected to a light emitting diode within the pixel in order to detect a portion of the luminous flux that is generated by the light emitting diode. The photodiode discharges excess charge within the pixel in response to the detected portion of luminous flux. Once the excess charge is discharged, the light emitting

diode stops emitting light. In an embodiment, the gate of a drive transistor is controlled by the charge on a storage node. If the charge on the storage node sets a voltage that exceeds the threshold voltage of the drive transistor then the drive transistor conducts. The amount of charge on the storage node above that which is needed to set the threshold voltage is referred to as the excess charge.

Brief Summary Text (16):
As long as the excess charge is present, the drive transistor conducts and the light emitting diode emits a luminous flux. However, when the excess charge is discharged from the storage node the voltage on the storage node drops below the threshold voltage of the drive transistor, the drive transistor stop conducting, and the light emitting diode stops emitting a luminous flux. The amount of luminous flux generated by the light emitting diode can be controlled by controlling the amount of excess charge that is placed on the storage node. Because the excess charge on the storage node is discharged in proportion to the amount of luminous flux that has been received by the photodiode, the luminous flux of the pixel is insensitive to the variation in characteristics of the drive transistor and the light emitting diode. The insensitively to the variation within each pixel of an active matrix pixel array allows the array to provide a more uniform luminous flux across the display.

Brief Summary Text (17):
In an embodiment, the active matrix pixel includes an address line, a data line, an address transistor a drive transistor, a storage node, an OLED, and a photodiode. The address line allows the pixel to be individually addressed and the data line provides the voltage to activate the drive transistor. The capacitor does not necessarily represent a separate physical component, but can represent the capacitance of the gates and junctions connected to the storage node. The drive transistor conducts as long as the voltage on the storage node exceeds the corresponding threshold voltage of the drive transistor. It should be understood that although a single active matrix pixel is described, the single pixel is typically part of an array of pixels that are located closely together in order to form a display.

Brief Summary Text (18):
The photodiode is optically coupled to the OLED so that the photodiode can detect a portion of the light that is generated by the OLED. The photodiode discharges the excess charge that is present on the storage node at a rate that is proportional to the luminous flux that is generated by the OLED. Because the photodiode discharges the excess charge on the storage node in proportion to the luminous flux of the OLED, the drive transistor and the OLED are turned off when the integrated flux detected by the photodiode has reached a value that is equivalent to the excess charge that is on the data line.

Brief Summary Text (19):
In operation, the address line of the active matrix pixel is set high for a period of time that charges the storage node with a desired amount of excess charge. Once the storage node is sufficiently charged, the address line is set low, effectively isolating the storage node from the data line. The drive transistor begins to conduct current as soon as the threshold voltage of the drive transistor is exceeded. Current conducting through the drive transistor causes the OLED to give off a luminous flux. A portion of the luminous flux is detected by the photodiode and in response, the photodiode discharges the charge on the storage node at a rate that id directly proportional to the luminous flux that is detected by the photodiode. At the point where the integrated value of the detected luminous flux equals the excess charge on the storage node, the voltage on the storage node drops below the threshold voltage of the storage node. Once the voltage on the storage node drops below the threshold voltage of the drive transistor, current stops flowing through the drive transistor and the OLED stops generating light.

Brief Summary Text (20):
In an embodiment, an additional transistor, referred to as the isolation transistor, is connected to the logical complement of the address line. Connecting the isolation transistor to the logical complement of the address line, prevents the isolation transistor from turning on the drive transistor when the storage node is being written from the data line. With the isolation transistor in place, the action of

the photodiode controls the flow of current through the drive transistor and the OLED, and the OLED does not emit light until the address line goes low.

Drawing Description Text (4):
FIG. 3 is a depiction of an active matrix pixel that incorporates a photodiode in accordance with an embodiment of the invention.

Drawing Description Text (5):
FIG. 4 is a depiction of an active matrix pixel that incorporates a photodiode, wherein the data line is separated from the OLED by an additional transistor in accordance with an embodiment of the invention.

Drawing Description Text (6):
FIG. 5 is a depiction of an active matrix pixel that is controlled by a photodiode, wherein the data line is separated from the OLED by an additional transistor in accordance with an embodiment of the invention.

Drawing Description Text (7):
FIG. 6 is a cross-section of part of an active matrix pixel that includes a photodiode as described with reference to FIGS. 3-5.

Detailed Description Text (2):
FIG. 3 depicts an embodiment of an active matrix pixel that incorporates a photodiode 316. It should be understood that although a single active matrix pixel is shown for description purposes, the single pixel is typically part of an array of pixels that are located closely together in order to form a display. The active matrix pixel includes an address line 302, a data line 304, an address transistor 306, a drive transistor 308, a storage node 310, an organic light emitting diode (OLED) 312, and the photodiode. As described with reference to FIG. 2, the address line allows the pixel to be individually addressed and the data line provides the voltage to activate the drive transistor. The capacitor does not necessarily represent a separate physical component, but can represent the capacitance of the gates and junctions connected to the storage node. As with the circuit of FIG. 2, the drive transistor of FIG. 3 conducts as long as the charge on the storage node is high enough that the voltage on the storage node exceeds the corresponding threshold voltage of the drive transistor. The charge on the storage node that raises the voltage on the storage node above the threshold voltage of the drive transistor is referred to as the excess charge. In an embodiment, the circuit within each pixel is fabricated with a dense, low voltage CMOS process.

Detailed Description Text (3):
The difference between the circuit of FIG. 2 and the circuit of FIG. 3 is that the photodiode 316 has been added to the circuit of FIG. 3. The photodiode is optically coupled to the OLED 312 so that the photodiode can detect a portion of the light 318 that is generated by the OLED. The photodiode discharges charge that is present on the storage node 310 at a rate that is proportional to the luminous flux that is generated by the OLED. Because the photodiode discharges charge on the storage node in proportion to the luminous flux of the OLED, the drive transistor 308 and the OLED are turned off when the integrated flux detected by the photodiode has reached a value that is equivalent to any excess charge that has been placed on the data line.

Detailed Description Text (4):
In operation, the address line 302 of the active matrix pixel of FIG. 3 is set high for a period of time that charges the storage node 310 with a desired amount of excess charge. Once the storage node is sufficiently charged, the address line is set low, effectively isolating the storage node from the data line 304. The drive transistor 308 begins to conduct current as soon as the threshold voltage of the drive transistor is exceeded. Current conducting through the drive transistor causes the OLED 312 to give off a luminous flux, as represented by the light 314 emanating from the OLED. A portion of the luminous flux, as represented by the light 318, is detected by the photodiode, and in response, the photodiode begins to discharge the charge on the storage node at a rate that is directly proportional to the luminous flux that is detected by the photodiode. At the point where the integrated value of the detected luminous flux equals the excess charge on the storage node, the voltage

on the storage node drops below the threshold voltage of the storage node. Once the voltage on the storage node drops below the threshold voltage of the drive transistor, current stops flowing through the drive transistor and the OLED stops generating light. With appropriate choices of drive currents and discharge rates and by controlling the excess charge on the storage node, the turn off time of the drive transistor can be set to occur within the refresh interval of the display. If the efficiency of the OLED or the drive of transistor changes, the amount of excess charge on the storage node can be adjusted so that a constant luminous flux is maintained.

Detailed Description Text (6):
In the embodiment of the active matrix pixel of FIG. 3, the photodiode 316 begins to regulate the emission of light from the OLED 312, as described above, at the moment the address line 302 goes low. However, during the time that the address line is high and current is flowing through the data line 304 to the storage node 310, the OLED emits light that is unregulated by the feedback action of the photodiode. The unregulated emission of light may be insignificant if the address time is a small fraction of the refresh interval.

Detailed Description Text (7):
FIG. 4 is a depiction of an embodiment of an active matrix pixel that minimizes the unregulated emission of light during the time that the address line is high. The components in the active matrix pixel of FIG. 4 are the same as the components in the active matrix pixel of FIG. 3 except that the active matrix pixel of FIG. 4 includes an additional transistor 420 and an additional resistor 422. Components in FIG. 4 that coincide with components in FIG. 3 are numbered similarly. In an embodiment, the additional transistor, referred to as the isolation transistor, is connected to the storage node 410 by its gate and to the logical complement of the address line 424 at its source. In another embodiment, the isolation transistor may be connected to V.sub.dd at its source. In the active matrix pixel of FIG. 4, the charge on the storage node controls the gate of the isolation transistor. When the charge on the storage node is sufficient to raise the voltage on the storage node above the threshold voltage of the isolation transistor, the isolation transistor can conduct. Connecting the isolation transistor to the logical component of the address line prevents the isolation transistor from turning on the drive transistor 408 when the storage node is being written from the data line 404. With the isolation transistor implemented as shown in FIG. 4 the photodiode 416 controls the flow of current through the drive transistor and the OLED 412, and the OLED does not emit light until the address line 402 goes low. That is, when the excess charge on the storage node has been discharged by the photodiode, the isolation transistor stops conducting and the gate of the drive transistor goes low. Connecting the resistor to ground as shown in FIG. 4 is necessary so that the drive transistor can turn off after the isolation transistor is open. Although shown as a resistor in FIG. 4, the component may alternatively be a MOS transistor configured to provide the appropriate resistance according to methods known to those skilled in the art.

Detailed Description Text (9):
In the active matrix pixel of FIG. 3, the threshold voltage of the drive transistor sets the lower limit of the dynamic range of the circuit. However, in the active matrix pixel of FIG. 4, the threshold of the isolation transistor 420 sets the lower limit of dynamic range of the circuit. Because the isolation transistor sets the lower limit of the dynamic range, there is no need to increase the threshold voltage of the isolation transistor to accommodate any voltage higher than V.sub.dd. The active matrix pixel of FIG. 4 may provide a wider dynamic range than the active matrix pixel of FIG. 3 when it is necessary to use a drive transistor with either higher thresholds or greater variability.

Detailed Description Text (10):
FIG. 5 depicts an embodiment of an active matrix pixel that incorporates a photodiode 516 and an isolation transistor 520 similar to the active matrix pixel of FIG. 4. Components in FIG. 5 that coincide with components in FIGS. 3 and 4 are numbered similarly. The active matrix pixel of FIG. 5 differs from the active matrix pixel of FIG. 4 in that a bipolar transistor is utilized as the drive transistor 508. The bipolar transistor of FIG. 5 replaces the NMOS transistor and resistor combination of FIG. 4. The bipolar transistor is easily added to a CMOS process. As

with the active matrix pixels of FIGS. 3 and 4, excess charge placed on the storage node 510 controls the luminous flux that is generated by the OLED 512. Current gain and other variables associated with the bipolar transistor have negligible effects on the luminous flux. The role of the bipolar transistor is solely to withstand V.sub.LED and the bipolar transistor does not need to provide high gain or operate at high frequencies. The lack of demand for either high performance or tight control makes it advantageous to add a bipolar transistor to a CMOS process. In an embodiment, the n-well of the drive transistor is used as a collector and the emitter is formed with the NMOS source and drain implants. The only additional processing steps may include an implant to form the base.

Detailed Description Text (11):
The use of photodiodes 316, 416, and 516 to control the luminous intensity of each pixel in an array of pixels as described with reference to FIGS. 3-5 requires that each photodiode collect light from its corresponding OLED, but not light from other pixels in the array. Furthermore, it is preferable to minimize the amount of light needed by the feedback circuit and maximize the collection efficiency of the display. FIG. 6 is a cross-section of part of an active matrix pixel that includes a photodiode as described with reference to FIGS. 3-5. The cross-section includes an OLED 602, a transparent insulator 604, a reflective metal layer 606, a photodiode, and an address transistor. The OLED sits on the transparent insulator over the layer of reflecting metal. Small openings 608 are patterned in the metal layer to allow light from the OLED to pass to the photodiode formed by an n+ diffusion 610 and a p substrate 612. As shown in the FIG. 6, the photodiode may be a simple extension of the address transistor 306, 406, and 506. The gate 614 and interconnection 616 to the address transistor are shown in FIG. 6. The ratio of the thickness of the reflective metal layer to the diameter of the opening can be chosen to confine the illumination of the substrate to the photodiode. The reflective layer and openings serve to block light from adjacent pixels, and to prevent light from affecting operation of the transistors in the pixel. In the case of color displays employing, for example, red, green, and blue OLEDs, different opening sizes may be selected for different colors. Because the opening sizes determine the fractions of total luminous flux collected by the photodiodes, different sizes for different colors may compensate for differences in quantum efficiency of the OLEDs and photodiodes. In this manner, the same circuit design and voltage levels are suitable for pixels of each color, in spite of the different efficiencies of the OLED materials and wavelength dependencies of the photodiodes.

Detailed Description Text (14):
The active matrix pixels as described with reference to FIGS. 3-6 allow an OLED to be driven at approximately 3-10 volts by adding either thin-film MOS transistors or bipolar transistors to a CMOS process that operates down to approximately 1.5 volts. The active matrix pixels, as described with reference to FIGS. 3-6, also allow the regulation of luminous flux from each pixel by adding a photosensor to the driving circuit of each pixel. The photosensors compensate for the variation of luminous flux in each pixel and for variations in some characteristics of the driving elements, which would otherwise make the luminous flux non-uniform. In particular, the photosensors make the luminous flux generated by the OLEDs insensitive to the transconductance of the thin film MOS transistor or the current gain of the bipolar transistor added to solve the voltage problem. The insensitivity and the lack of need for high frequency response allow bipolar transistors to be utilized with minimal extra processing and cost.

CLAIMS:

1. An active matrix pixel within an active matrix display comprising:

a light emitting diode, that is specific to a pixel of said active matrix display, for generating luminous flux;

means, that is specific to said pixel, for storing an excess charge; and

means, that is specific to said pixel and optically connected to said light emitting diode, for detecting a portion of said luminous flux that is generated by said light emitting diode, and for discharging said excess charge in response to said detected

portion of said luminous flux.

4. The active matrix pixel of claim 1 wherein said light emitting diode is an organic light emitting diode, and wherein said means for detecting is a photodiode formed within said pixel to receive said portion of said luminous flux.

5. The active matrix pixel of claim 4 further including a reflective layer between said light emitting diode and said photodiode, with said reflective layer having an opening that allows said portion of said luminous flux to be detected by said photodiode.

13. An active matrix pixel within an active matrix display comprising:

an address line;

a data line;

a storage node for storing an electrical charge;

an address transistor having a gate that is activated from said address line, a source that is connected to said data line, and a drain that is connected to said storage node;

a drive transistor having a gate that is responsive to said storage node;

a light emitting diode connected to a circuit that includes said drive transistor, wherein said light emitting diode emits a luminous flux when said drive transistor completes said circuit; and

a photodiode that is optically connected to said light emitting diode in order to receive a portion of said luminous flux that is emitted from said light emitting diode, and that is electrically connected to said storage node in order to discharge said electrical charge on said storage node in proportion to said portion of said luminous flux that is received by said photodiode.

20. The active matrix pixel of claim 13 further including a reflective metal layer that is located between said light emitting diode and said photodiode, said reflective metal layer having an opening that enables said portion of said luminous flux to be received by said photodiode.